PB83-194696

Weathered IXTOC I Oil
Effects on Estuarine Benthos

Texas Univ. at Austin

Prepared for

Environmental Research Lab.
Gulf Breeze, FL

24 Oct 81

U.S. Department of Commerce
National Technical Information Service
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TECHNICAL REPORT DATA
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1. REPORT NO. EPA-600/J-82-032	2. JOURNAL ARTICLE
3.	PB83-134696
4. TITLE AND SUBTITLE WEATHERED IXTOC I OIL EFFECTS ON ESTUARINE BENTHOS	5. REPORT DATE 1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Richard D. Kalke, Thomas W. Duke, & R. Warren Flint	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS The University of Texas Marine Science Institute Port Aransas, Texas 78373	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory Gulf Breeze, FL 32561	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE EPA/600-1

15. SUPPLEMENTARY NOTES

Estuarine, Coastal and Shelf Science (1982) 15:75-84

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT Distribute to public	19. SECURITY CLASS (This Report) unclassified	21. NO. OF PAGES 11
	20. SECURITY CLASS (This page) unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

Reprinted from *Estuarine, Coastal and Shelf Science* (1982) **15**, 75–84

EPA-600/J-82-032
JOURNAL ARTICLE

Weathered IXTOC I Oil Effects on Estuarine Benthos[a]

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Received 17 June 1981 and in revised form 24 October 1981

Keywords: hydrocarbons; oil pollution; benthic survey; redox; estuarine; benthos; colonization

The impact of weathered IXTOC I oil on experimental benthic communities colonized in the laboratory and *in situ* was observed. Test systems containing clean sand and receiving seawater from Aransas Pass Inlet were placed in the laboratory while similar systems were placed on the seafloor. All of these test systems were allowed to colonize for 8 weeks by settlement of planktonic larvae. Weathered IXTOC I oil was added to randomly selected laboratory and *in situ* replicate compartments within the test systems and these were then exposed to flowing seawater in the laboratory for an additional 4 weeks. Observations of the structure and biomass of the communities at the end of the 12-week period indicated no significant effects on the laboratory colonized communities. However, total density was significantly affected in the *in situ* colonized systems as was species composition. Although not significant, total biomass was substantially reduced by oiling. Eh measurements of sediments showed that the oil reduced the depth of the oxygenated layer approximately half. This reduction may reduce subsurface benthic production and alter processes such as nutrient regeneration.

Introduction

The dispersal of pollutants into aquatic ecosystems has had far-reaching effects and continues to present potential risks to the environment. Aquatic monitoring studies to date have ranged from expensive multidisciplinary research programs to single species monitoring and to laboratory-controlled bioassays. Informative techniques, including the above, for measuring the environmental effects of pollutants fall short in meeting the present demands of scientific inquiry or legal mandates imposed upon environmental managers.

Our approach in monitoring and developing an understanding of south Texas Gulf estuarine/coastal systems has been to focus on the benthic habitat. The reasons for emphasizing the benthos are numerous but include its important role in nutrient cycling and secondary production within marine ecosystems. Aquatic research indicates that activities of benthic fauna (e.g. bioturbation) contribute to such processes as nutrient regeneration (Aller, 1978;

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Aller & Yingst, 1978; Gallepp, 1979; McCaffrey *et al.*, 1980) which link the benthos to ecosystem functioning and increase the importance of the benthos in respect to benthic–pelagic coupling and overall production of these ecosystems (Rowe, 1978). In addition, the biomass produced by fauna living in the sediments serves as an important link in many living resources of marine ecosystems (e.g. Arntz, 1980) including the Gulf of Mexico (Flint & Rabalais, 1981).

The IXTOC I oil spill in the Bay of Campeche, and resultant transport of weathered oil to south Texas Gulf waters in the summer of 1979, presented an ideal opportunity to employ our techniques using experimental benthic communities to evaluate the impact of this weathered oil on the environment. Since the majority of oil eventually collected in the intertidal zones of south Texas beaches, or settled to the shallow subtidal seafloor, we felt that experimental benthic communities would provide an ideal monitoring tool to assess the effects of the oil on this part of the ecosystem. We believed that our experimental design would also complement field studies of intertidal beach infauna that were conducted during the spill (e.g. Thebeau *et al.*, 1981; Rabalais & Flint, in preparation) by providing information on the potential sublethal effects to invertebrates that could only be gained from controlled laboratory manipulation. In addition, information collected from these experiments could be used to gain some insight concerning potential longer-term impacts to the entire coastal ecosystem which were suggested from short-term field monitoring of the spill (Chapman, 1981; Thebeau *et al.*, 1981; Gundlach *et al.*, 1981). Our goal was to allow benthic species colonization to occur under controlled conditions. These developed communities would then be used to test both the acute and chronic effects of IXTOC I oil collected from south Texas beaches.

Methods

Four sets of experimental benthic test systems, each containing 10 replicate compartments, as described by Hansen (1974) were filled to depths of 7 cm with azoic sediments that were allowed to dry for 35 days with periodic washings of freshwater. These sediments were of a similar grain size to the bottom sediments of the estuary from which unfiltered water was pumped to supply continuous flow to our laboratory facilities. Two of the four sets of test systems were placed in the laboratory and received this unfiltered continuous water flow at a rate of 200 ml min^{-1}. The other two systems were placed on the estuarine bottom in a water depth of approximately 4 m. Both the laboratory and *in situ* systems were allowed to colonize through settlement of larvae for 8 weeks, from 5 December 1979 to 4 February 1980. At the end of this period, the *in situ* systems were covered, retrieved by SCUBA and placed in the laboratory with the other two systems on the continuous flow water supply at the same flow rate. Ambient water temperatures and salinities were maintained in the laboratory at all times and a light/dark cycle simulating natural conditions was adhered to.

Oil, identified as coming from the IXTOC I well blowout using carbon isotope ratios (K. Winters, Marine Science Institute, personal communication), was collected in large quantities in the intertidal zone of Padre Island beaches on 6 November 1979. Samples of this oil were analysed for saturated and aromatic fractions of total hydrocarbons at the beginning of treatment and at the conclusion of the experiments. Oil was extracted from the wet sand with benzene. The proportion of oil to sand in these samples was 1 : 9 (10%). After evaporation of the benzene, the oil was fractionated by silica gel column chromatography. The silica gel was eluted successively with two column volumes of hexane and then benzene to give saturate and aromatic fractions respectively. The fractions were then

analysed by gas chromatography on a Perkin-Elmer 910 Gas Chromatograph and electronic integration of the peak areas was performed by a Hewlett-Packard 3352B Data System.[a]

After stabilization of all systems in the laboratory (2 days) following colonization of the laboratory and *in situ* systems respectively, replicate compartments from the laboratory colonized and *in situ* colonized test systems were selected using a random numbers table (Sokal & Rohlf, 1969) for treatment. This selection excluded the two end compartments in each test system because of possible end-of-row effects. A total of 32 compartments from each of the two sets of differing colonization procedures were used for the experiments and 16 of these were treated with oil by layering 600 g of weathered oil/sand mixture (60 g of oil) over the water surface of each compartment and allowing it to settle to the compartment's sediment surface.

After treatment with oil the experimental systems were maintained on the unfiltered seawater system for an additional 4 weeks. At the completion of this period sediment Eh measurements were made in four randomly chosen control compartments and four randomly chosen oil-treated compartments from both laboratory colonized and *in situ* colonized systems. These measurements were done to determine the depth of the redox potential discontinuity (RPD) layer as described by Rhoads (1974). Measurements were taken at 5 mm depth intervals through the sediment with a Radiometer TTT-26 Eh/pH meter, with a platinum/calomel electrode system. After these measurements, samples of oiled sediments were taken for hydrocarbon analysis, as described above, and all compartment sediments were then sieved through a 0·5-mm mesh, preserved and later examined for fauna according to Flint & Holland (1980). Biomass was measured on dominant fauna as well as the total community in each replicate after correction for 15% weight loss due to formalin preservation (Mills & Fournier, 1979).

Species lists of each replicate compartment for control and treatment test systems were compared using cluster analysis, employing the Canberra–Metric similarity index with a flexible sorting strategy (Flint, 1981). Species diversity of each replicate was calculated by the Shannon–Wiener index (Pielou, 1966) using $\log_2$ and equitability (Lloyd & Ghelardi, 1964). Community parameters and individual faunal densities and biomasses were compared for differences between treatments using one-way analysis of variance.

Results

The oil/sand mixture used in these experiments was well weathered as contrasted to oil that first appeared on south Texas beaches during the summer of 1979 from the IXTOC I blowout (Figure 1). The gas chromatograph of the benzene fraction of the summer 1979 oil spill contained a considerable amount of the volatile fractions which are often correlated with acute toxicity (Jordan & Payne, 1980). The chromatographs of the oil samples taken at the initiation and conclusion of our laboratory experiments (Figure 1), however, no longer exhibited the presence of these fractions.

In comparing the hexane fraction of the treatment oil initially and at the conclusion of the experiments (Figure 2), apparently light weathering had occurred during the treatment period. This is especially apparent at the lower carbon levels on the chromatograph. This weathering was attributed 20% to microbial degradation and approximately 80% to physical breakdown (K. Winters, Marine Science Institute, personal communication).

[a]Mention of tradenames here and elsewhere in this paper does not imply endorsement by the EPA.

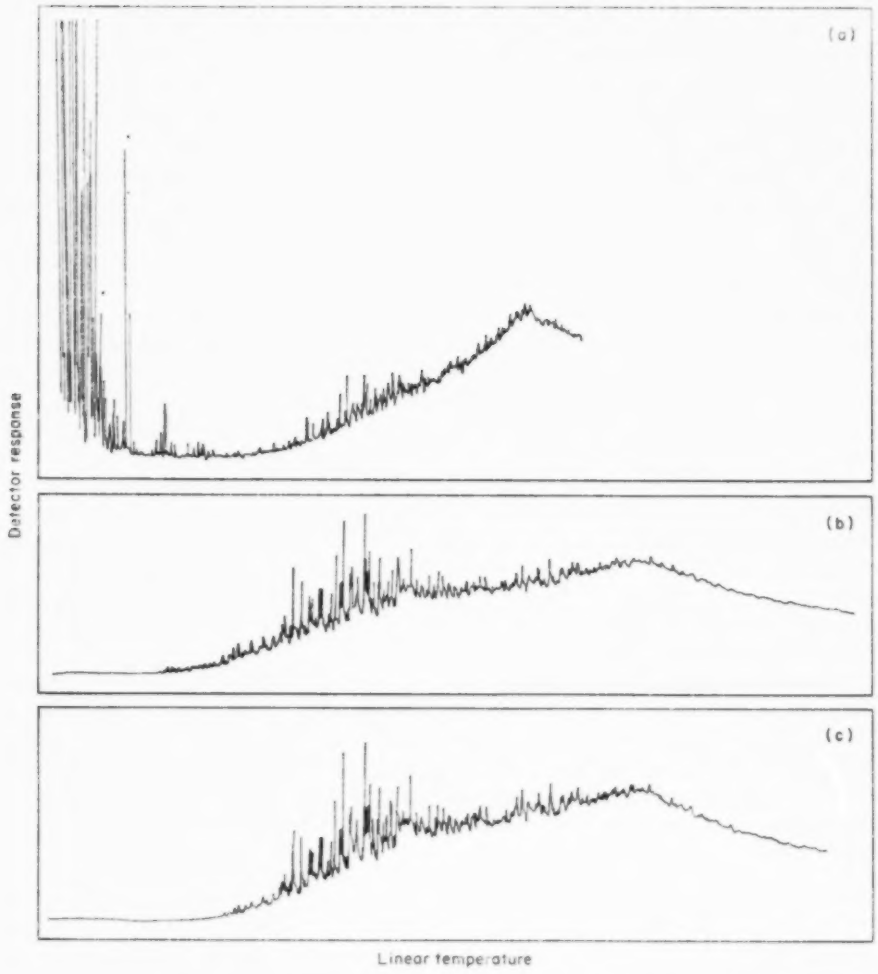

Figure 1. Benzene fraction gas chromatographs of IXTOC I oil (a) impacting south Texas beaches (6 August 1979), (b) used for treatment of benthic communities at the beginning (6 February 1980) and (c) end of laboratory treatments (4 March 1980).

Hierarchical classification techniques fused the laboratory colonized compartments and the ***in situ*** colonized compartment into two different clusters according to species assemblages at the 82% dissimilarity level (Figure 3). In the laboratory compartments, clustering of replicates resulted in a random distribution of the control and treated replicates, suggesting no real development of a pattern related to the oil treatment in these benthic communities.

The results of Table 1 for the laboratory colonized compartments further verified the observations from cluster analysis (Figure 3). For all benthic community variables plus most individual species densities, there was no significant difference ($P < 0.05$) between

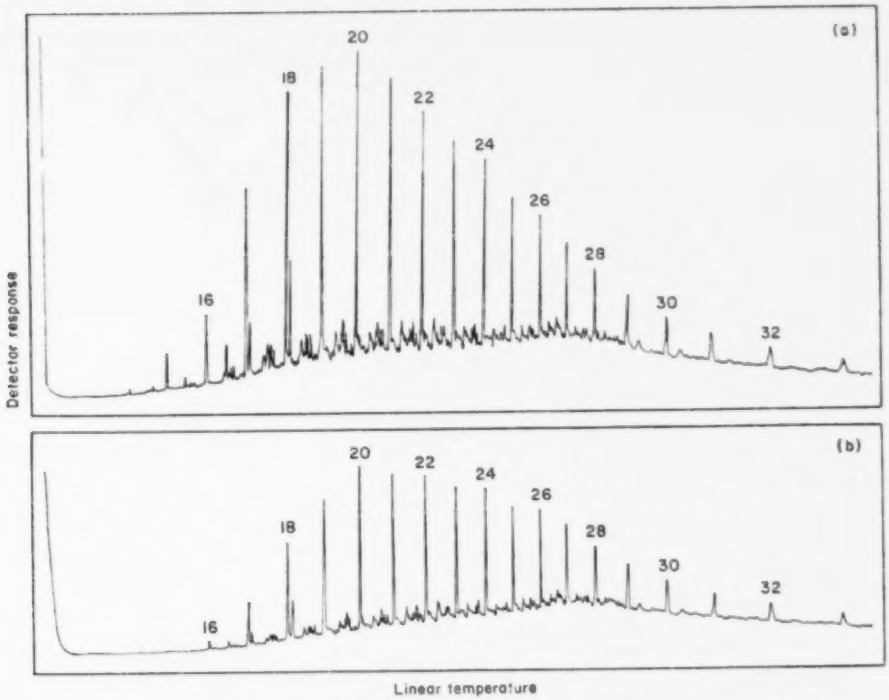

Figure 2. Hexane fraction gas chromatographs of the IXTOCI oil used for treatment of benthic communities (a) at the beginning (6 February 1980) and (b) the end (4 March 1980) of the laboratory experiments.

controls and oil treatment. Most of the community variables, including species number, total density and total biomass, were all lower for the laboratory replicates than for the *in situ* replicates (Table 1) and were significantly different in all cases.

The hierarchical classification for the *in situ* colonized replicates (Figure 3) showed a much more definable pattern than in the laboratory replicates. Six of the eight control compartments were clustered together and distinct from the eight treatment compartments at a dissimilarity level of approximately 20%. Thus, benthic species composition of the control communities was different from the oil-treated communities.

Examination of the general community variables and individual densities for dominant populations in the *in situ* colonized compartments (Table 1) further supported the observations from cluster analysis. Number of species did not show a difference between control and oil-treated replicates but total infaunal density did. Although not significantly different, total biomass exhibited higher standing stocks for control replicates, corresponding to the higher density levels. In addition, the density of the two most dominant benthic fauna, *Abra aequalis* and *Balanoglossus* sp., also showed significant differences ($P < 0{\cdot}05$) between treatments and controls. The third most dominant fauna in these *in situ* compartments (*Corophium acherusicum*), however, did not show a difference in density between control and treatment replicates (Table 1). In all cases where there were differences in densities or biomass, the oil treated replicates always exhibited lower numbers.

Eh profiles taken at the end of the experiment (Figure 4) showed that the RPD layer in the laboratory and *in situ* control sediments ranged from 30 to 40 mm depth. In contrast, the oil-treated sediments for both types of colonization exhibited RPD layers between 10 and 20 mm sediment depth.

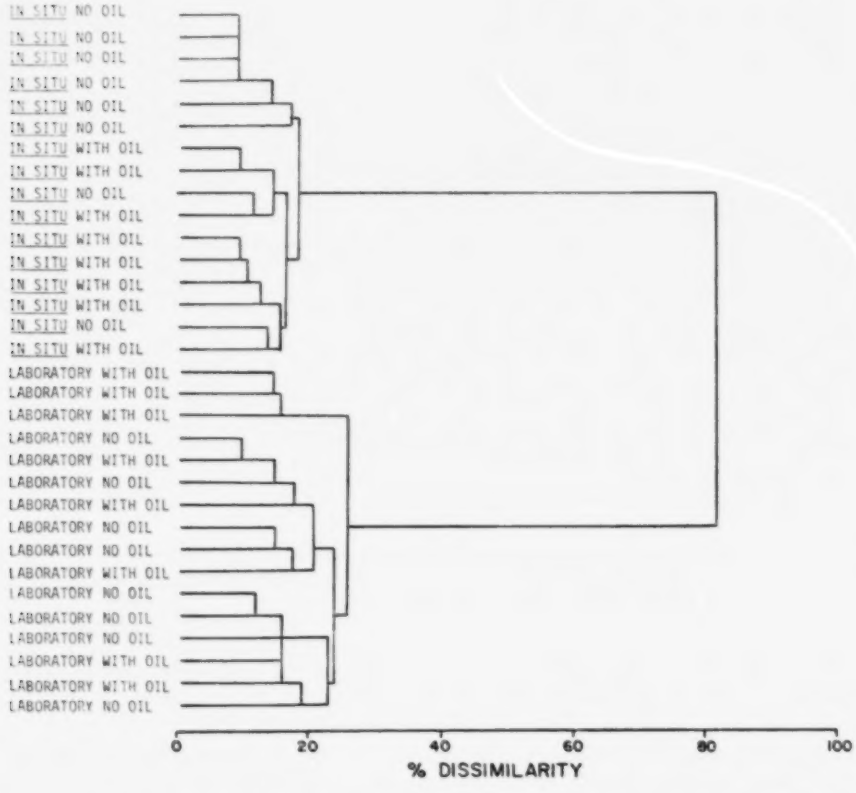

Figure 3. Cluster analysis dendrogram comparing species lists of estuarine benthic communities both treated with IXTOC I oil and untreated.

Discussion

The weathered oil used in these experiments was apparently not acutely toxic to the benthic fauna that colonized the test systems for the 4-week exposure period. This is verified by the laboratory colonized results which showed no difference between any of the parameters examined (Table 1). The volatile portion of the benzene fraction, which is usually responsible for acute toxicity (Jordan & Payne, 1980), was low in the test oil compared to the first oil that impacted Texas beaches in the summer of 1979 (Figure 1). Only slight changes in the benzene and hexane fractions of the test oil were observed following the 4-week test period and these changes were attributed to microbial degradation and physical breakdown.

TABLE 1. Mean and standard deviation of benthic community variables and population densities for estuarine benthic species assemblages treated with weathered IXTOC I oil for 4 weeks after an 8-week colonization period. Numbers in parentheses for each species density represents that species percentage of total infaunal biomass for that treatment

	Laboratory colonized		*In situ* colonized	
	Control	Oil-treated	Control	Oil-treated
Species number	19·3 ± 4·8	19·6 ± 3·6	47·4 ± 3·9	44·8 ± 3·8
Total density	593·1 ± 164·6	686·8 ± 214·1	6445·3 ± 1502·4	3723·8 ± 653·2
Total biomass	671·9 ± 472·7	550·0 ± 276·9	4337·4 ± 853·9	3509·4 ± 671·5
Species diversity	2·60 ± 0·16	2·61 ± 0·09	1·49 ± 0·25	1·73 ± 0·18
Equitability	0·78 ± 0·04	0·79 ± 0·02	0·43 ± 0·10	0·49 ± 0·08
Abra aequalis density	136·0 ± 33·0 (24)	153·7 ± 46·7 (22)	4703·2 ± 1217·3 (72)	2524·3 ± 569·8 (67)
Balanoglossus sp. density	169·7 ± 74·0 (30)	226·5 ± 93·9 (32)	1247·3 ± 447·1 (18)	579·0 ± 225·6 (18)
Mulinia lateralis density	72·5 ± 43·3 (13)	142·8 ± 86·8 (20)	100·5 ± 48·1 (2)	82·0 ± 51·9 (2)
Corophium acherusicum density	94·8 ± 48·4 (17)	96·2 ± 47·8 (14)	217·8 ± 136·8 (3)	226·8 ± 101·4 (6)
Mediomastus californiensis density	—	0·2 ± 0·4	67·7 ± 37·5 (1)	34·8 ± 14·1 (1)
Anemone density	30·8 ± 18·3* (5)	20·0 ± 8·0* (3)	35·8 ± 10·1 (1)	14·5 ± 6·7*
Spiophanes bombyx density	29·7 ± 21·3 (5)	14·5 ± 9·1 (2)	22·5 ± 17·4	11·3 ± 8·3

* or underline indicates no significant difference between treatments at $P < 0.05$.

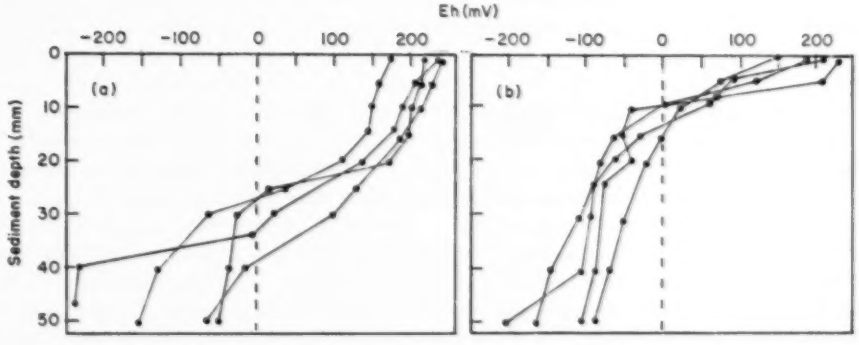

Figure 4. Eh profiles of benthic test system sediments both untreated (a) and treated with IXTOC I oil (b). The 0-mV level indicates the redox potential discontinuity (RPD) layer.

Sorting of the species lists with cluster analysis fused the laboratory and *in situ* colonized compartments into two discrete groups, suggesting that these groups were different, probably due to the different modes of colonization. While the same dominant species were present from both forms of colonization, the overall species number and density were lower in the laboratory. The *in situ* control replicate results suggested that the laboratory dominant faunal densities did not represent peak carrying capacities for these species in the habitat examined. The difference in these results was related to the laboratory colonists being supplied via a water pump, while the *in situ* colonists were able to naturally settle from the plankton or move into the compartments from surrounding sediments.

The random grouping of species lists in the laboratory control and treatment compartments resulting from cluster analysis suggested that there were no acute effects of the weathered IXTOC I oil on these communities at the population densities which occurred. These conclusions were further verified by the observations on the laboratory replicates in Table 1. If there had been toxic effects from the oil at least some of the parameters measured should have shown a difference between treated and control replicates, but none were noted.

At the population densities found in the *in situ* compartments there was an apparent effect from the oil treatment as indicated by cluster analysis groupings as well as the results of Table 1. Although in general, community structures were not that different between control and oil-treated *in situ* replicates, densities of many similar fauna between the treatments were, causing the separations observed (Figure 3).

While densities of *Abra aequalis* and *Balanoglossus* sp., the most dominant species in all replicates, were not effected by oil treatment in the laboratory colonized test systems, their densities were significantly lowered in the *in situ* oil-treated compartments. This difference could be attributed to effects of the oil treatment on the RPD layer and its ultimate effect on habitat space for some of the species.

According to Eh profiles (Figure 4) the treated sediments had a much shallower RPD layer contrasted to the controls. The layering of IXTOC I oil over the sediment surface resulted in an oxygenated layer approximately half the depth of that found in the control sediments. The results when compared to the significant decrease in density of dominant subsurface dwellers such as *Abra aequalis* and *Balanoglossus* sp., suggested that although the oil was not directly acutely toxic to the fauna, the tolerable habitat space for subsurface dwellers had been significantly reduced, causing a reduction in their total population densities. Further evidence for this conclusion comes from the data on the third dominant population, the sediment surface dweller *Corophium acherusicum*, which did not have its habitat space reduced by oil treatment. This species usually lives in tubes constructed on the sediment surface (Bousfield, 1973). While the layering of oil on the sediment surface physically altered the surface structure, it had no significant effect on *C. acherusicum* population densities.

Further evidence for this conclusion on reduced habitat space comes from the laboratory colonized compartments (Table 1). In contrast to *in situ* colonized replicates, no differences were observed between the densities of any of the dominant fauna for control *vs.* oil-treated sediments. In addition, the densities of *A. aequalis* and *Balanoglossus* sp. were much lower in these replicates than in the *in situ* colonized replicates (Table 1). Since as already discussed, these populations were not at peak carrying capacity, when the RPD layer became shallower in the treated replicates, these populations still had sufficient habitat space for their densities without losing any numbers. This appears to be a valid conclusion since the *in situ* colonized treatment replicates still supported 2–10 times higher densities in the reduced subsurface habitat space than the control or treated laboratory colonized compartments for these two populations.

In conclusion, although these experiments did not exhibit acute toxicity to benthic communities from weathered IXTOC I oil, the oil treatments resulted in:

(i) reduced subsurface benthic production available to higher trophic levels;
(ii) reduced oxygenated subsurface sediment layers which may result in altered processes such as nutrient regeneration at the mud–water interface; and
(iii) reduced sediment surface area due to the physical presence of the oil.

These observations coupled with field studies conducted during the IXTOC I spill period suggest that the decrease in infaunal densities observed at many sampling sites along the south Texas coastal beaches (Thebeau *et al.*, 1981) could have resulted from alteration in the physical environment due to the presence of IXTOC oil patches as much as to direct toxicity of the oil.

Acknowledgements

We wish to thank K. Winters for hydrocarbon analyses and S. Rabalais for taxonomic assistance. Additional thanks are given to L. Tinnin for manuscript preparation. We also acknowledge the careful review of this manuscript by M. Bender and an additional anonymous reviewer.

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Printed in Great Britain by Henry Ling Ltd., at the Dorset Press, Dorchester, Dorset